INTERFERENCE AVOIDANCE IN MC-DS-CDMA

A Thesis submitted in partial fulfillment of

the requirements for the degree of

Master of technology

in

Electronics and Communication Engineering

Specialization: **Communication and Networks**

by

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Rourkela, Odisha, 769 008, India
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Under the guidance of

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Certificate

This is to certify that the work in the thesis entitled **Interference Avoidance in MC-DS-CDMA** by **Ankit Kumar** is a record of an original research work carried out by him during 2014 - 2015 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Electronics and Communication Engineering** (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela

Date:

Prof. (Dr.) Siddharth Deshmukh
Dept. of Electronics and Communication
National Institute of Technology Rourkela

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Finally, I humbly bow my head with utmost gratitude before the God Almighty who always showed me a path to go and without whom I could not have done any of these.

ANKIT KUMAR

Abstract

Recent trends in wireless communication have led to the shift in attention towards multicarrier modulation. In this thesis, the multicarrier communication used is hybrid MC-DS-CDMA in which the information data is spread in both time and frequency domain. These types of spreading code are termed as two dimensional orthogonal variable spreading factor (2D-OVSF) codes. This hybrid CDMA is having the advantages of both MC-CDMA and MC-DS-CDMA.

In this thesis, we are going to characterize another metric-*MAI Coefficient* which will anticipate the effect of MAI with the time and frequency domain spreading in a particular channel. With the assistance of this MAI coefficient, a novel interference avoidance code assignment strategy is proposed. By mutually considering the acquired MAI impact and the blocking probability in the code tree structure, the proposed strategy can successfully decreasing the MAI for the multi-rate MC-DS-CDMA framework, while keeping up great call blocking rate execution.

Contents

Nomenclature

C[]	OVSF code
f(x)	Generator polynomial
λ	Arrival rate
μ	Departure rate
Φ	Maximum spreading factor
$P_B(\Phi)$	Call blocking probability
P_s	Steady state probability
g(t)	Time domain spreading code
N	frequency domain spreading factor
M	Time domain spreading factor
T_o	Bit duration of reference user
T_k	Bit duration of interfering user
P_k	Transmitted power
$b_k(t)$	Rectangular pulse of data symbol
$r_o(t)$	Received signal
N_o	Power spectral density of AWGN
β	weight of Maximal ratio combining
$I_{k,s,v}$	Multiple access interference

Abbreviations

3G	Third Generation.
AWGN	Additive White Gaussian Noise.
BER	Bit error rate
BPSK	Binary Phase Shift Keying.
CDMA	Code Division Multiple Access.
CF	Crowded First
DS	Direct Sequence.
DSSS	Direct sequence spread spectrum
FDD	Frequency Division Duplex.
GSM	Global System for Mobile.
ISI	Inter-Symbol Interference.
MAI	Multiple-Access Interference.
MC	Multicarrier
MCM	Multicarrier modulation
MRC	Maximal Ratio combining
OCSF	Orthogonal single spreading factor
OFDM	Orthogonal frequency division multiplexing
OVSF	Orthogonal variable spreading factor
FDSC	Frequency domain spreading code
TDSC	Time domain spreading code
TDMA	Time division multiple access
FDMA	Frequency division multiple access

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1
Introduction

1.1 Background:

Spread Spectrum technique, has been mainly used in military services, increases the bandwidth of the transmitted signal, thus getting the word “spread”, significantly so as to make the signal appear noise like.

Traditionally, Multiple access technique for mobile communications, had been deployed as Time division multiple access (TDMA) and Frequency domain multiple access (FDMA). In TDMA, the transmission channel is isolated into diverse time openings. Each user is allocated their own time slots to transmit their data. In FDMA, the allocated frequency spectrum is divided into different frequency slots which can be used by different users.

The above techniques fails to impress in current scenario because of the exponential rise in number of users and hence, capacity. The increasing demand for capacity brings us to the need of CDMA in which multiple users can transmit as well as use a channel simultaneously by modulation of their information data within the same bandwidth. The demonstration of CDMA can be seen in Figure 1.1.

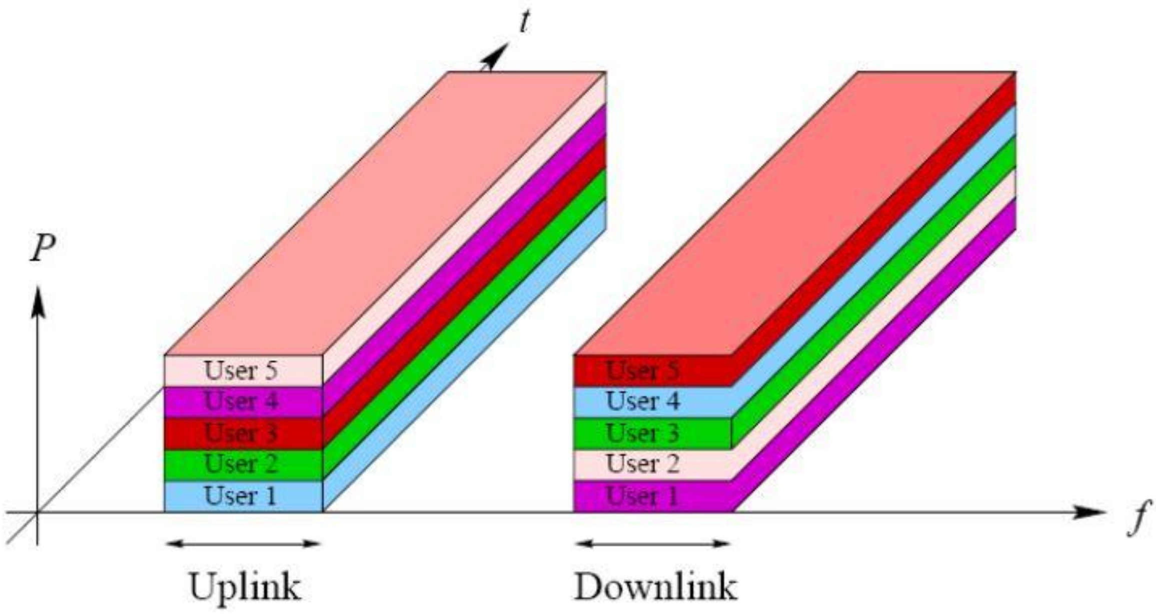

Fig 1.1: brief demonstration of CDMA

In CDMA, as the name suggests, a pseudo random code is assigned to each user of the system which are orthogonal to the code of the anther user. The orthogonality of the code ensures minimum Multiple Access Interference (MAI) between the users so that information of each user is distinguishable at the receiver. But, in the practical scenario, even if the codes are designed to be perfectly orthogonal, the multipath propagation channel increases the cross-correlation, thereby, destroying the orthogonality between the codes. This can be taken as the major disadvantage of CDMA over traditional techniques TDMA and FDMA.

The most widely used CDMA technique is direct sequence spread spectrum (DSSS) or Direct sequence CDMA (DS-CDMA). In DS-CDMA, the information signal, usually binary in nature, is multiplied with a pseudo random code. The multiplication of the code with the data spreads the signal by the length of the code, is known as the spreading factor of the code. The below figure 1.2 demonstrates the spreading phenomena.

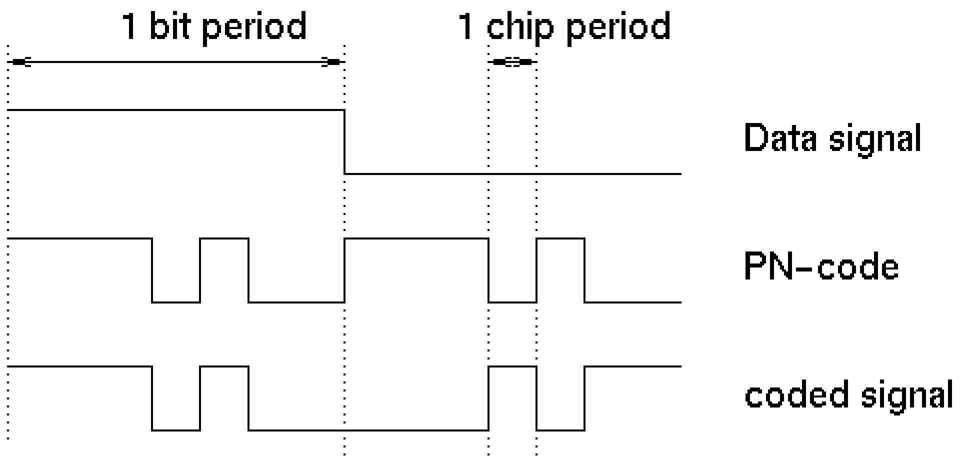

Fig. 1.2: Spreading phenomena in CDMA

Due to spreading, the bandwidth of the signal increases due to which the bandwidth of the signal exceeds the bandwidth of the channel. Due to this high data rate demand in current mobile environment, Multicarrier modulation scheme, also known as orthogonal frequency-division multiplexing (OFDM) has been drawing a lot of attention.

1.2 Literature survey:

The demand for high data rate has led the communication world to shift its attention towards multicarrier modulation (MCM). It was first introduced in early 1950s for military communications. In MCM, the information signal is split into several components and then each component is sent over different carrier signals known as sub-carriers. Each sub-carrier has narrow bandwidth, but the overall signal becomes wideband. The major advantages of MCM may be immunity over multipath fading and ISI whereas disadvantage includes synchronization problem of the carriers under marginal conditions.

Two methods were used to overcome the problems faced in DS-CDMA, namely Multicarrier CDMA (MC-CDMA) and Multicarrier DS-CDMA (MC-DS-CDMA).

The MC-CDMA technique is mainly linking between time domain spreading and MCM. Here, each data symbol is serial to parallel converted and then spread before being transmitted over different subcarriers whereas in DS-CDMA, data symbol was just spread and transmitted serially over a single carrier. MC-DS-CDMA basically is a combination of MCM and time domain spreading in which the data symbol is first spread in time domain and then modulated over different subcarriers. In other words, DS-CDMA is a unique case of single carrier MC-DS-CDMA.

Now, we define a trade-off between the above two discussed methods which would be referred to as hybrid MC-DS-CDMA which is having the advantages of both the systems. In this system, the data symbol is expanded in both time domain and frequency domain before being transmitted.

1.3 Objective of the work

The main objective of this work is to introduce a new algorithm which would improve the BER response of the MC-DS-CDMA without disturbing the compactness of the OVSF tree structure. Following analysis has been done to support the above statements:

- Generations of OVSF codes and check the autocorrelation and cross-correlation between related and un-related codes.
- BER analysis of MC-DS-CDMA
- Introduce code placement techniques, namely- Random, leftmost and crowded-first to reduce the code blocking probability.
- Introduce a new metric system- MAI coefficient, which would smartly predict the incurred MAI before the assignment of a particular code.

- Compare the effect of the introduction of the MAI coefficient on the BER response and code blocking probability.

1.4 Thesis organization:

The thesis report is divided into five chapters. The first four chapters cover the theoretical part and their corresponding simulated results, if applicable and the last part deals with the conclusions and future works related to the corresponding project.

- **2D-OVSF:**

In this chapter, there is a brief discussion about OVSF codes and their correlation properties, then there will be discussion about two dimensional OVSF tree and details about related codes in an OVSF tree.

- **Code placement:**

This chapter discusses the proper utilization of the OVSF codes in limited resource to check probability of a call being blocked. In initial discussions, we will see the types of code placement techniques and then comparison of these techniques under different conditions.

- **MC-DS-CDMA:**

In this chapter we will discuss about MC-DS-CDMA in detail. In the initial parts, we will discuss the basics and the transmitter and receiver models of the technique. Then the BER analysis of the technique is also done under different conditions.

- **MAI:**

This section will analyze the multiple access interference on multicarrier MC-DS-CDMA and method to suppress the MAI. To look into the MAI $I_{k,s,v}$, we need to have in depth idea about the relationship between the bit length of time of the reference client and the bit span of the client which is meddling i.e relationship between T_o and T_k for kth interfering user. Now, there can two possible cases. One, if the data rate of the interfering user is greater than the reference user and second, if the data rate of the interfering user is less than that of the reference user.

- ## Conclusion and future work:

In this chapter we will discuss the final conclusions related to our project work about how the call blocking is affected by our code assignment strategy and then then we will discuss about the scope of future works related to our project work.

2
2D-OVSF

In this chapter, there is a brief discussion about orthogonal variable spreading factor (OVSF) codes and their correlation properties, then there will be discussion about two dimensional OVSF tree and details about related codes in an OVSF tree.

2.1 Basics:

In the 2nd generation mobile systems, each user is assigned a single orthogonal constant spreading factor (OCSF) codes. But the use of these codes limit the service to low bit rate and voice data. So, for higher data rate services, such as file transfer and QoS guaranteed multimedia applications, variable data rate support should be there in the system. So, this multirate system can only be supported by the use of variable length spreading codes. These codes are referred to as Orthogonal variable spreading factor (OVSF) codes. OVSF has the ability to support both variable as well as higher data rates. The schematic which can explain an OVSF code tree can be seen in the figure below:

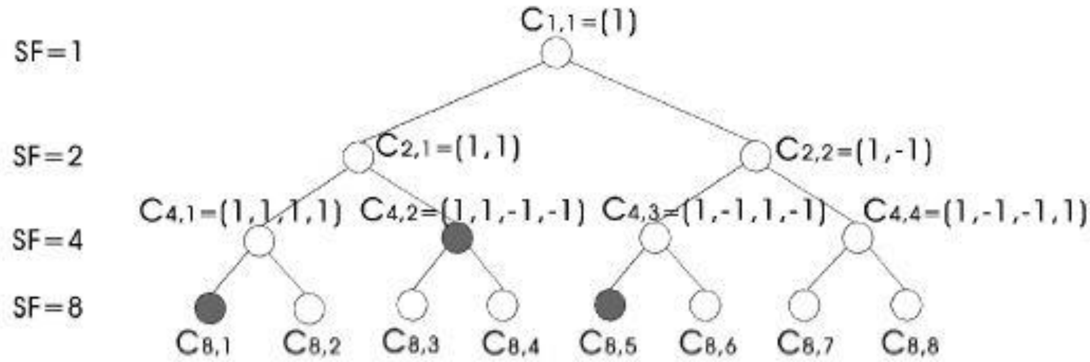

Fig 2.1 OVSF tree

As shown in the figure above, we can see that each code in the tree branches itself into two different codes, both of which are orthogonal to each other. The code formed after branching further sub-divides into two other codes which are again, orthogonal to each other. This process keeps continuing till the code having the maximum spreading factor length is attained. In the figure, we can see that code tree has different layers having code lengths from one to maximum spreading factor increasing with the power of two. Basically, one layer in the tree altogether forms a Walsh-Hadamard code matrix.

As seen in the figure, the OVSF code tree has spreading factor ranging from one to eight. The first layer of the tree has spreading factor of one and this code is divided into two parts as [1 1] and [1 -1]. Both these codes are orthogonal to each other. Now again, both these codes are divided into two parts which makes a total of four codes as [1 1 1 1], [1 1 -1 -1], [1 -1 1 -1] and [1 -1 -1 1]. When we analyze the orthogonality of these four codes, we will find that these four codes are also orthogonal to each other. The orthogonality between these codes can be seen in the figure below which has been derived using simulation:

The dividing of these codes will keep on continuing until the length of the codes reaches the maximum spreading factor. The desired spreading code will be allocated to a particular user according to the data rate being requested by that user.

Now if two users are requesting codes having different data rates, then the next issue arrives regarding the orthogonality between the different length spreading codes. For this, let us define related codes. The sub-tree derived from the original code can be said to be related to each other. The original code would be termed as the parent or ancestor code and the codes which are the part of sub-tree are known as child codes. For example, as taken in the above demonstration, [1 1] is the parent code of the codes [1 1 1 1] and [1 1 -1 -1] and in vice versa mode these codes are children code of [1 1].

The necessity of defining related codes is that there will be orthogonality problem in between these related codes resulting to multiple access interference. This problem has been solved using a new metric- MAI coefficient which has been discussed in upcoming chapters.

2.2 2D-OVSF

In the time domain and frequency domain spreading of MC-DS-CDMA, the code tree will be having a two dimensional structure as shown in the figure2.2.1. In this figure, we are using frequency domain spreading code as 4 and time domain spreading code are OVSF codes whose spreading factor varies from 1 to 8. The construction of these time domain or frequency domain spreading codes can be done using the one dimensional OVSF code rule as seen in [17]. The orthogonality of the codes has already been discussed in the previous section, but in two dimensional environments, let us analyze the orthogonality of the OVSF codes.

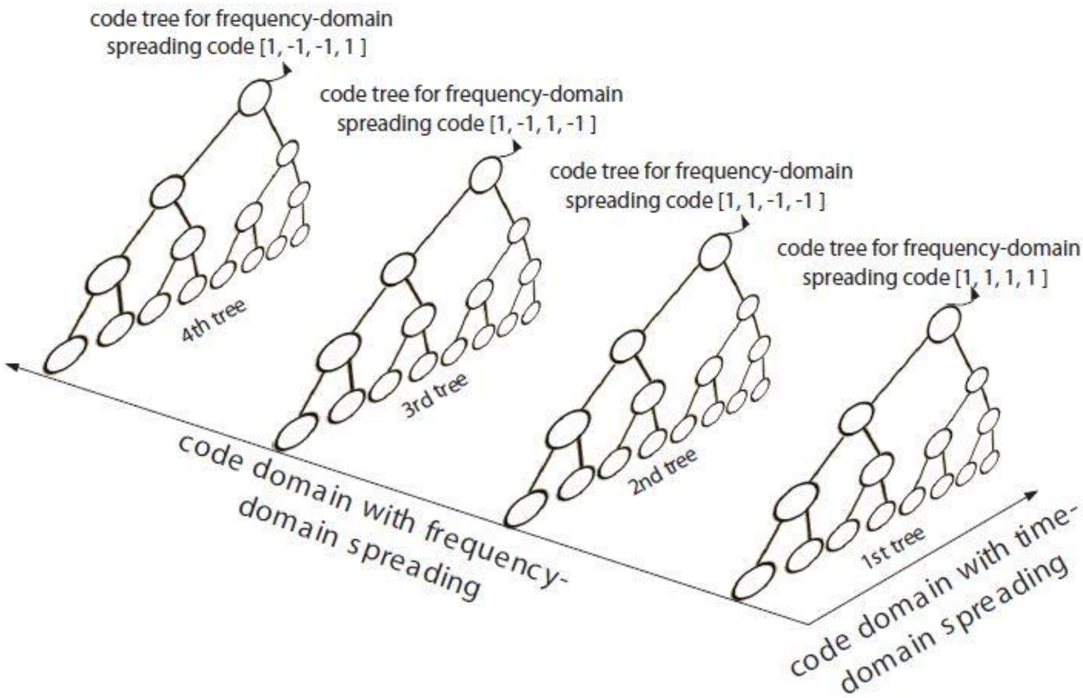

Fig 2.2 2D structure of OVSF tree

To ease the illustration, the two dimensiomal code tree is merged into one as in the figure below:

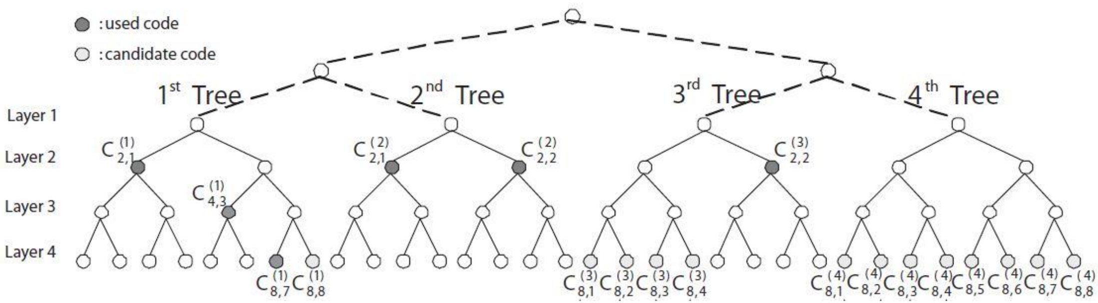

Fig 2.3 2D-OVSF tree in single frame

Now, the total spreading factor of the code tree is SF_t x SF_f. in the figure, the SF_f to 4 and SF_t is equal to 1~8. So, here the OVSF tree in time domain is replicated 4 times for each of the associated FDSC. Frequency domain codes are generally taken as walsh-hadamard codes, hence, we can say that they are orthogonal to each other. But due to frequency selective Rayleigh channel, there is generally loss of orthogonality . in that case, the orthogonality may not always stand true.

Now, let us discuss the related codes concept in two dimensional OVSF codes. We can say that two codes are orthogonal if the codes are having parent-child relationship in time dpmain.

The above explained concept can be explained in a better way through grid representation of the OVSF codes.

Here, we are going to introduce grid representation of the time domain and frequency domain spreading codes for MC-DS-CDMA. In lattice representation, the code assets are meant by set of rectangular boxes of variable sizes according to the length of the OVSF codes. The sizes of the rectangular boxes are directly proportional to the data rate requested by the user which in contrarily relative to the spreading component length of the time space code. The basic grid representation can be seen in the figure below:

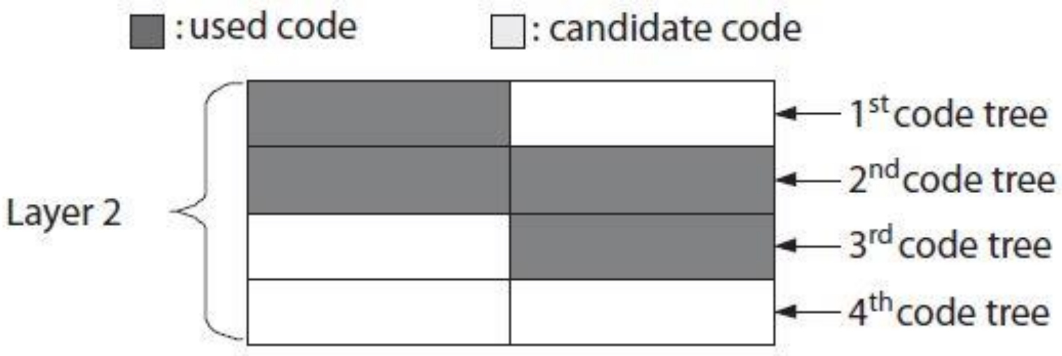

Fig 2.4 Layer 2 in grid representation of an OVSF tree

In the above figure, we can see that each row is representing the frequency domain spreading code i.e. there are four codes hence four trees. Each row consists of two rectangular boxes which is denoting layer two of the time domain OVSF codes, each having a length of two. The shaded boxes are representing the used codes whereas the white boxes are giving unused codes which can act as candidate codes. Further layer representation of the time domain OVSF codes can be done as below:

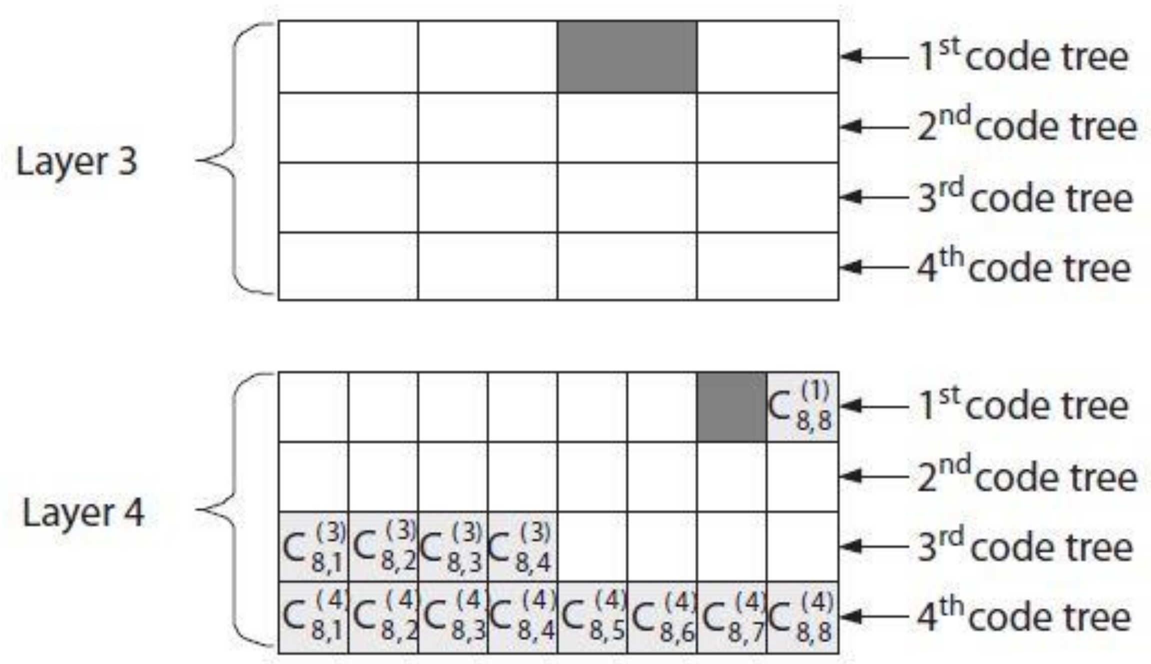

Fig 2.5 Layer 3 and 4 in grid representation of the OVSF tree

We can see that as the length of time domain codes are increasing, the area of the rectangular boxes are decreasing are thus, is straightforwardly corresponding to the asked for information rate by the client. The aggregate of the rectangular boxes, i.e. from spreading factor 2~8, along with the free and used codes, can be summarized in the figure below:

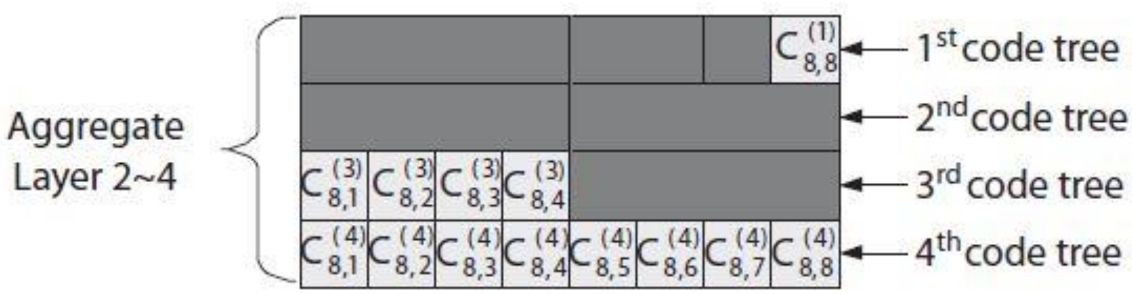

Fig 2.6 Combined layers in grid representation of the OVSF tree

So, for two dimensional OVSF codes, related codes are those used codes which are situated in the same segment of the network representation. For example, $\{C_{8,8}^{(1)}, C_{2,2}^{(2)}, C_{2,2}^{(3)}, C_{8,8}^{(4)}\}$ are positioned in the right most column. They a set of related codes and are prone to interference.

3
Code Placement

This chapter discusses the proper utilization of the OVSF codes in limited resource to check probability of a call being blocked. In initial discussions, we will see the types of code placement techniques and then comparison of these techniques under different conditions.

3.1 Basics:

In this chapter we are going to find an environment where each OVSF code is available to every call. For every OVSF code, the data rate of the user is of the power of two and varies inversely according to the spreading code length. The main issue in the allocation of the OVSF codes is the code placement which mainly deals with how to place a new call to the codes available in the code tree because since the resource is limited, the code tree would get fragmented which may affect the utilization of the code tree.

Let use define the main problem encountered in placing a call. Give us a chance to say another call arrives which is asking for a free code of rate kR, our undertaking will be to allot a free code from the given OVSF tree. The code placement technique mainly addresses the code allocation policy when there is more than one codes are available to be allocated in the code treewhen no free code is available, the situation leads to a condition when the new call cannot take place. This condition is known as call blocked which will reject the upcoming call.

To counter the code placement issues in CDMA systems, our general approach will be to make the tree as compact as possible so that the tree could support more calls in the given resources. By achieving this, the tree would incur less call blocking probability. Three strategies have been discussed to overcome the code placement problem, namely, random, left-most and crowded first. In the random placement technique the code is assigned to a random position in the tree which are free. This system is essentially utilized for correlation purposes to different methods. The leftmost technique tries to accommodate the code in the leftmost available free code in the OVSF code tree. Whereas, in the crowded first technique, a code is assigned to the position whose subtree has minimum free code available

According to the simulation results, we will see that crowded first and leftmost code placement strategies are performing pretty much well as compared to the random strategy. Let us discuss all the three mentioned strategy in detail.

3.1.1 Random strategy:

On the off chance that another call is asking for a code of information rate kR, where k is of the force of two, this strategy searches for free codes in the OVSF tree and then randomly assigns one of the code of the respective data rate to that new call. If the tree cannot accommodate the call, since there is no free code available of that data rate, then the call will be blocked and hence rejected.

Since this strategy is not very efficient and generally used for reference purposes, this strategy is not used and better options are available discussed in the next section.

3.1.2 Leftmost strategy:

If a new call is requesting a code of data rate kR, this technique basically starts accommodating the new calls to the leftmost side of the code tree and next call will be accommodated in next right of the previously allocated code, if available. This is done to accommodate the higher data rate calls in the right hand side of the code tree.

3.1.3 Crowded first strategy:

In this strategy, if the call requests a new call of data rate kR, then basically, we will check the ancestor codes of all the free codes of that particular data rate i.e. data rates of (k-1)R. the ancestor code which has least capacity available will be picked. Specifically, if the requested call has the options of the free codes x and y of data rate kR, then we will check their respective ancestor codes x_o and y_o. the ancestor code which will be having least free capacity will be picked. In the event that there a case emerges, that there is a tie number of free codes, then we will go one level up and check the precursor codes of xo and yo. this system is rehashed until we get the subtree with the base free limit. There is a special case where the ancestor codes of x and y are same, then we will pick the code with the leftmost code placement strategy which will pick the code on the left hand side.

Let us make the above procedure with the help of an example. Consider a tree as shown in the figure below:

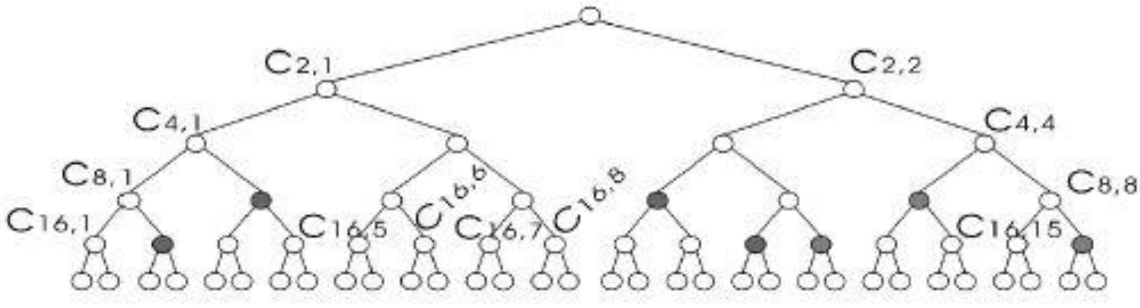

Fig 3.1 Example to show crowded first technique

Suppose, a new call is requested for data rate 2R, so the available codes are $C_{16,1}, C_{16,5}, C_{16,6}, C_{16,7}, C_{16,8}, C_{16,15}$. By the crowded first technique, we will compare the ancestor codes of these codes. From the figure above, we can see that the ancestor codes $C_{8,1}$ and $C_{8,8}$ are having least free codes when compared to other available codes. But when we observe the number of least free available free codes, we will find a tie in the number. So again, we will compare the ancestor codes of the ancestor codes, i.e. $C_{4,1}$ and $C_{4,4}$. Again we will find equal number of least free codes. So we will go one level up again, and then we can see, from the figure that, $C_{2,2}$ is having lesser capacity when compared to $C_{2,1}$. So finally, $C_{2,2}$ will be assigned to the requested call.

3.2 Markov chain:

In this chapter, we will make an analytical model for the call to setup. For achieving this, let us consider a tree of maximum spreading gain of eight, i.e. the calls are having their transmission rates ranging from 1R to 8R. Every requested call of different transmission rates will have their own arrival, service as well as departure rates. So our significant objective will be the talk of the call blocking likelihood and transmission capacity usage of the OVSF tree. Our approach, irrespective of the code placement strategy used, will be a general one. The simulation result of the desired goal will be seen in the next chapters.

The general methodology will be displayed utilizing a Markov chain. For this, condition of the OVSF tree must be characterized. The condition of the tree signifies the current condition of the tree what codes are utilized and what is the remaining limit of the tree. The indication of the states is given by th succession of numbers. Case in point, if there are three calls dynamic in the framework having transmission rates 8R, 4R and 1R, then the condition of the framework will be given as (841) and if there are four brings in the framework having transmission rates 4R, 4R, 1R and 1R, then the state would be given as (4411). In any case, we might likewise express that the request of the representation is not so much be the administration request. The above calls can have the state representation as (4141) or (1441). We can say this on the grounds that the aggregate total of the state numbers lets us know the remaining limit in the code tree. In any case, it is essential, whether confused, the quantity of individual transmission rates ought to be same. Case in point the state (4411) is not equivalent to (4222) in light of the fact that they are having diverse codes and consequently, they may have distinctive landing and administration rates.

In the figure below, we have listed the states of the codes when the maximum spreading factor is 32:

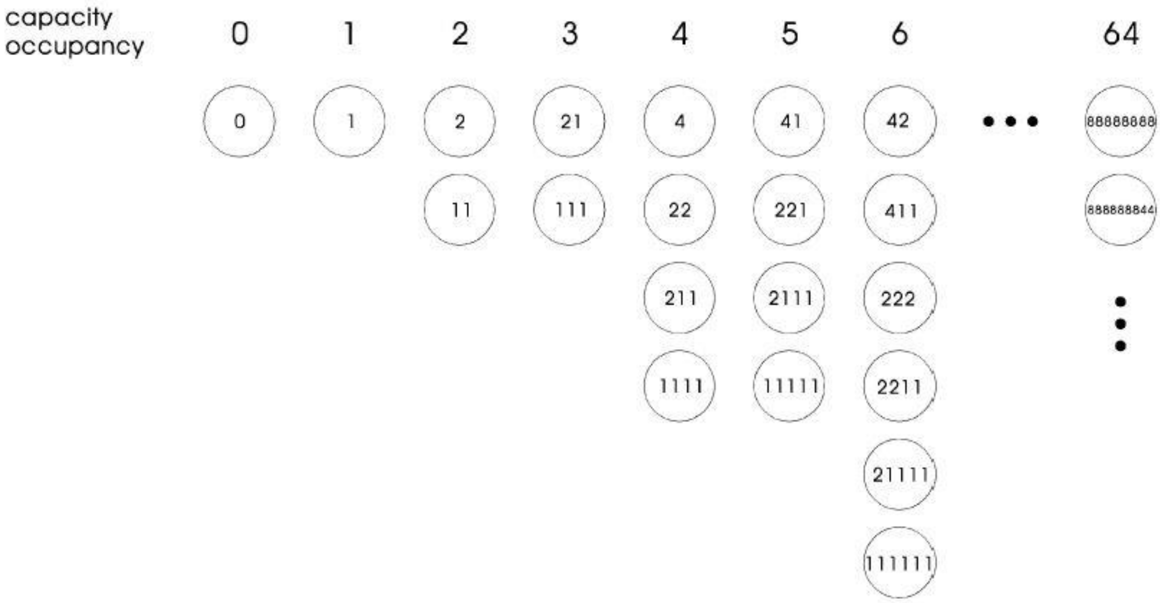

Fig 3.2 Example to show capacity occupancy

The grouping is done on the basis of the total occupied codes depending upon the capacity of the code tree. The state of the code should have the sum equal to the capacity of the code tree. The tree cannot accommodate any more code such that its sum exceeds the total capacity. For example, if the system can accommodate the total capacity of 6, then the possible states for the code tree can be given as (42), (222), (411), (21111) , (2211) and (111111). To define all the possible states in a system, we can give a generator polynomial as follows:

$$f(x) = \frac{1}{1-x} \times \frac{1}{1-x^2} \times \frac{1}{1-x^4} \times \frac{1}{1-x^8} \qquad (3.1)$$

The coefficient of x_c in f(x) can be used for calculating the number of states which is having a total capacity of C. for the interpretation of the calculation of integer partition problem with parts 1,2,4 and 8 can be attempted[5]. One point to be noted is that the coefficient of the polynomial is independent of the maximum spreading factor because f(x) is not affected by it. Using the above method, we can get the aggregate number of states in the framework utilizing the whole of the coefficients of x_c in C. the demonstration for total number of states has been shown in the figure below for different sizes of the code tree having a system occupancy of cR.

Till now, we have got the knowledge of state of the OVSF tree. Our next step is to make the state diagram after generating all of the possible states. Let us discuss the concept of state diagram using an example.

The example is shown in the figure below:

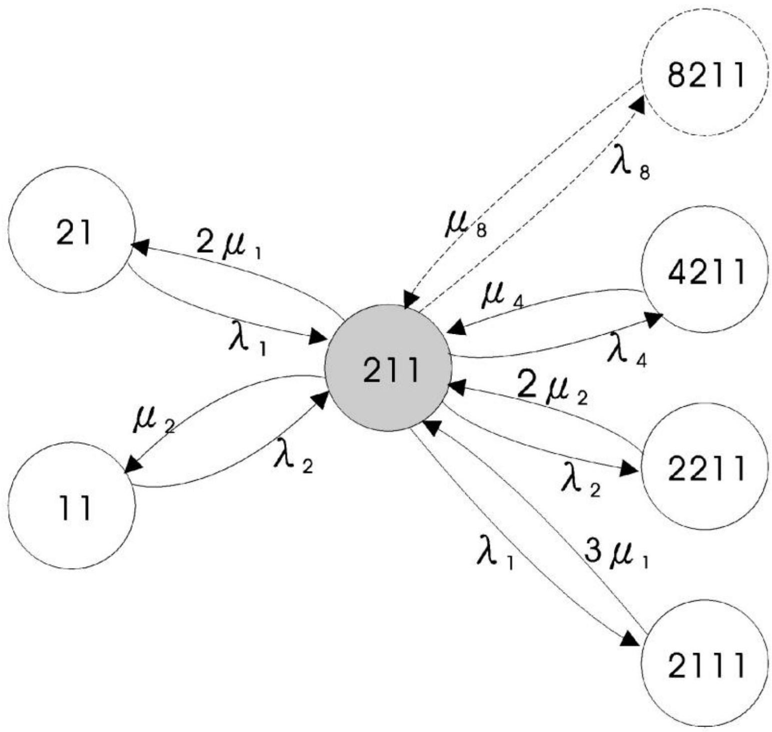

Fig3.3 Example to show Markov chain

Assume that the maximum spreading factor is 8 and the current state of the code tree is (211). In the figure, we can see that all the possible transitions going in and going out of the assumed state has been shown. Any new call arrives to the system with a rate known as arrival rate. Usually it is denoted by λ_i. Once the call has arrived, it is in the system for a specific amount of time. The rate of the time the call is in the system is known as service rate. Usually it is denoted by μ_i. We can see that for every new call requested having a different transmission rate is having their arrival and service different to each other. Also the requested call having transmission rate which is not feasible to be accommodated is represented using dashed line in the state diagram. Also we are considering that every call arrives using poisson process and depart in accordance with exponential process.

The expression used for the process in arrival and departure can be seen below:

a. Poisson process: For a finite amount of time t, the number of arrival in poisson process is given by:

   P = $\frac{(\lambda t)^n}{n!} e^{-\lambda t}$

b. Exponential process: For a finite amount of time t, the number of departures in exponential process is given as:

   P = $e^{-\lambda t}$

There are the required notations to explain the transitions. They can be summarized as seen below:

a. Φ: maximum spreading factor
b. λ_i: the arrival rate of calls using poisson process
c. μ_i: the service rate for calls having transmission rate iR
d. P_s: The steady /state probability for the OVSF code tree to remain in the state s
e. F(s,i) is the feasible function, where s is representing the state of the system and i is 1,2,4 or 8.

   Such that, F(s,i) = $\begin{cases} 1 \; if \; C_{s+i} \leq \Phi \\ 0 \; otherwise \end{cases}$ (3.2)

   {This function denotes whether adding a new call of transmission rate iR is legal or not. The illegal

state is when the new state sum after adding

a new call exceeds the total capacity of the system.

This illegal state is denoted by 0}

Also, if we add the steady state probabilities of all the states, it will result to 1:

i.e. $\sum_{\forall s} P_s = 1$

The solution of above equation will lead us to the steady state probability P_s for every state s. In the next topics we will discuss call blocking probability and bandwidth utilization.

3.2.1 Call blocking probability:

As we have earlier discussed, a call is blocked when if there is no free space left for a new call to accommodate in the OVSF tree. In other words, the blocking takes place when a new call is requested by the system but the addition of that code will lead the system to get drawn to the illegal state. The illegal state depends upon the maximum spreading factor. The accumulated probability for a given spreading factor such that $0 \leq i \leq \Phi$, where i is an integer, is given as:

$$P_a(\mathrm{i}) = \sum_{\forall s: C_s = i} P_s \quad (3.3)$$

The above expression tells us the addition of all the states present in the system which are having the occupying capacity of *i*. for example, if the total capacity occupancy is 6, then the expression for occupying probability is given as:

$$P_{\mathrm{a}}(6) = P_{(222)} + P_{(42)} + P_{(411)} + P_{(2211)} + P_{(21111)} + P_{(111111)} \quad (3.4)$$

The expression for call blocking probability is given as:

$$P_B(\Phi) = \frac{\lambda_1.P_a(\Phi)+\lambda_2.\sum_{i=\Phi-1}^{\Phi} P_a(i)+\lambda_4.\sum_{i=\Phi-3}^{\Phi} P_a(i)+\lambda_8.\sum_{i=\Phi-7}^{\Phi} P_a(i)}{\lambda_1+\lambda_2+\lambda_3+\lambda_4} \quad (3.3)$$

3.2.2 Bandwidth utilization:

This equation tells the total bandwidth utilized by the OVSF codes tree. It is usually denoted by U_Φ. The bandwidth utilization can be derived by the division of addition of bandwidth utilization of the states which are having same capacity occupancy and the total capacity if the OVSF code tree. The expression for bandwidth utilization is given as:

$$U_\Phi = \frac{\sum_{i=1}^{\Phi} P_a(i).i}{\Phi} \quad (3.4)$$

3.3 Simulation results:

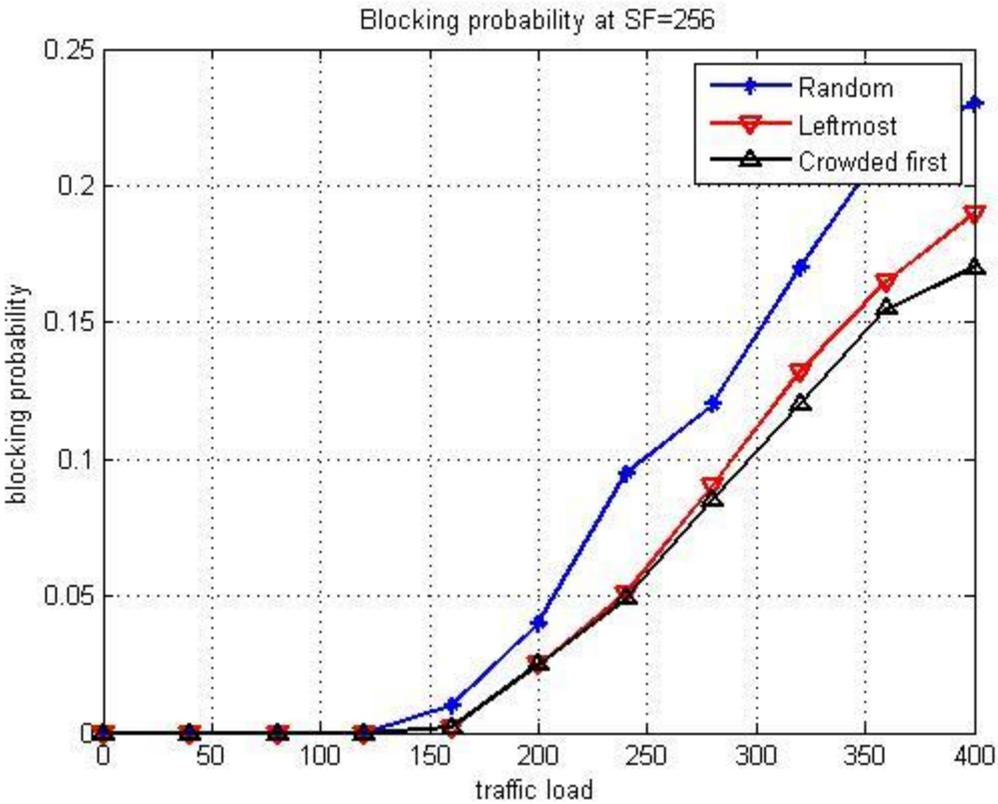

Fig3.4 Simulation result for blocking probability when SF=256

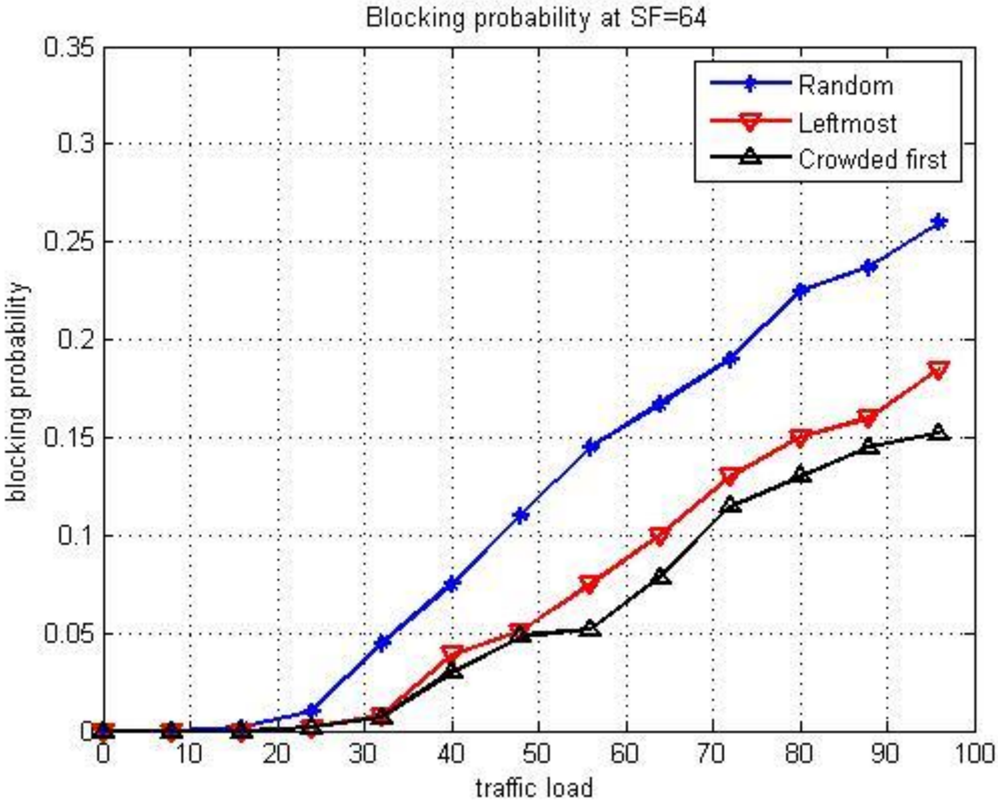

Fig3.5 Simulation result for blocking probability when SF=64

From the above figures, we can conclude that the best performance is given by crowded first code assignment strategy, followed by leftmost strategy and random strategy. In the figure, we can see that at lighter load, there is not much effect of code placement strategy on the blocking probability but, as the load on the system increases, there will have significant effects of placement strategy on the blocking probability.

4
Multicarrier DS-CDMA

In this chapter we will discuss about MC-DS-CDMA in detail. In the initial parts, we will discuss the basics and the transmitter and receiver models of the technique. Then the BER analysis of the technique is also done under different conditions.

4.1 Basics:

All the experiments are performed using hybrid MC-DS-CDMA which is having the characteristics of both MC-CDMA in which time domain spreading is done and MC-DS-CDMA in which frequency domain spreading is done. So, here basically we're going to deal with the CDMA technique in which both time domain as well as frequency domain spreading is done.

This hybrid system thus performs two dimensional spreading. The time domain spreading code (TDSC) is of length N and can be represented as $g_i(.)$ whereas the frequency domain spreading code (FDSC) is of length M and can be represented as $C_j[.]$. All the codes follow Non Return to zero (NRZ) pattern i.e. {1,-1}. The code set used for a certain user is $(g_i(.),C_j[.])$.

Now, the code set used for the desired user is $(g_1(.),C_1[.])$. The rest of the code set is broadly divided into three groups:

- Group A: When FDSC of other users are orthogonal to each other irrespective of the orthogonality of the TDSC. Mathematically, it can be represented as: $(g_1(.),C_2[.]).,(g_1(.),C_3[.]).,\ldots..(g_1(.),C_M[.])$ i.e. $j\neq 1$.
- Group B: When TDSC of other users are orthogonal to each other irrespective of the orthogonality of the FDSC. The mathematical demonstration of the codes may be given as: $(g_2(.),C_1[.]).(g_3(.),C_1[.])\ldots..(g_N(.),C_1[.])$ i.e. $i\neq 1$.
- Group C: When both TDSC and FDSC of other users are orthogonal to the desired user. Mathematically, it represents all of the remaining codes for $i\neq 1$ and $j\neq 1$.

Considering there are two type of codes used for spreading purpose i.e. TDSC and FDSC for a data symbol, the net spreading factor used for the symbol is the multiplication of the spreading factor of the two codes. So, the net spreading factor can be given as SF=MxN.

4.1.1 Transmitter model:

The transmitter structure of the two dimensional MC-DS-CDMA is demonstrated in the figure 2.1:

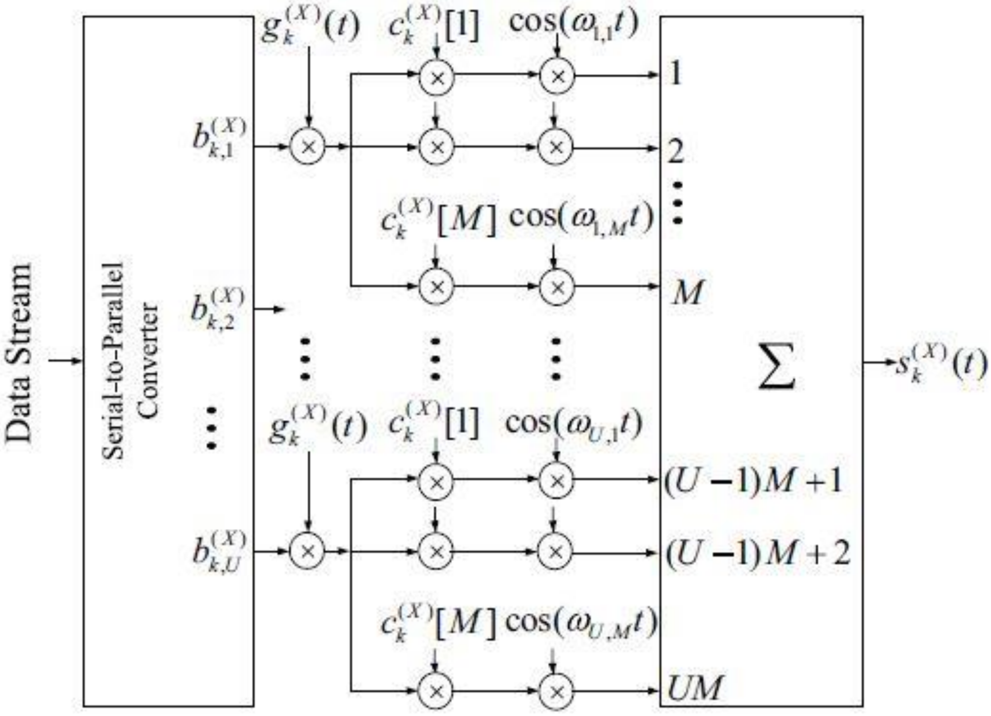

Fig4.1. Transmitter model of MC-DS-CDMA using both TDSC and FDSC

At first, the data stream is serial-to-parallel converted so that the data rate of the subcarriers. The main advantage of doing this is now each substream will experience independent flat fading.

The information rate is lessened by changing over stream of bit term Tb,k into U decreased rate parallel substreams of bit span Tk such that Tk=U*Tb,k for kth user. The data is now spread in time domain using TDSC, $g_k(t)$. This time domain spread code is copied to N subcarriers, since the FDSC length is N, and then each copied data if multiplied with FDSC $C_k[.]$.

Now, let us consider that our reference user is having their respective TDSC and FDSC as $g_o(t)$ and $C_0[.]$.Now, for the remaining users, we can categorize the three code set groups as:

- Group A: $\begin{cases} \frac{1}{\mathrm{To}} \int_0^{To} \mathrm{gk(t)go(t)dt} \neq 0 \\ \frac{1}{\mathrm{N}} \int_0^{N} \mathrm{Ck[.]Co[.]} = 0 \end{cases}$

- Group B: $\begin{cases} \frac{1}{\mathrm{To}} \int_0^{To} \mathrm{gk(t)go(t)dt} = 0 \\ \frac{1}{\mathrm{N}} \int_0^{N} \mathrm{Ck[.]Co[.]} \neq 0 \end{cases}$

- Group C: $\begin{cases} \frac{1}{\mathrm{To}} \int_0^{To} \mathrm{gk(t)go(t)dt} = 0 \\ \frac{1}{\mathrm{N}} \int_0^{N} \mathrm{Ck[.]Co[.]} = 0 \end{cases}$

One point to be noted is that the above equations are valid for downlink MC-DS-CDMA. Also, our main aim in the simulation is to get results for variable TDSC for a single FDSC. So, mainly we are going to concentrate for Group A code set. In other words, only a single frequency domain spreading code will be used so that system capacity will reduce to a larger extent.

The signal which will be transmitted for the k^{th} user will be given by the expression:

$$S_k(t) = \sum_{i=1}^{U} \sum_{j=1}^{N} \sqrt{\frac{2Pk}{N}} b_{k,i}(t) g_k(t) C_k[j] * \cos(2\pi f_{i,j} t + \psi_{k,i,j}) \tag{4.1}$$

where, P_k is transmitted power

$f_{i,j}$ is j^{th} subcarrier frequency

and, $\psi_{k,i,j}$ is the initial phase in the i^{th} substream uniformly distributed over $[0,2\pi]$

The i^{th} substream waveform is $b_{k,i}(t)$ which is basically a rectangular pulse of time duration T_k. Mathematically, it can be given as:

$b_{k,i}(t) = \sum_{h=-\infty}^{\infty} b_{k,i}[h]P_T(t-hT_k)$ where $b_{k,i}[h]=\pm1$ with equal probability

$g_k(t)$ is the TDSC giving the chip sequence of the rectangular pulse having time duration T_c. It can be mathematically written as:

$g_k(t) = \sum_{l=-\infty}^{\infty} g_k[l]P_{Tc}(t-lT_k)$ where $g_k[l]=\pm1$ with equal probability

From the above equations, we can conclude that the time domain spreading gain of user k is $G_k=T_k/T_c$

4.1.2 Receiver model:

In the frequency selective fading channel, increase in the cross correlation of TDSC and FDSC, or we can say that non orthogonality between the two dimensional codes results in multi-access interference (MAI) of the received signal. Here, we are setting up the environment for our ease such that two assumptions have been taken. One, we are assuming our single cell downlink transmission environment without any power control and second one that flat Rayleigh fading will be experienced by each subcarrier. In this atmosphere, the desired user is affected by multiple access interference via the desired user propagation path. So, path loss and MAI experienced will be same as that of the reference user. Now, as seen in [14]-[16], just for the simplicity in the modeling, we will neglect the effect of path loss and will be concentrating mainly on the multi access interference.

After taking the above assumptions, we can give the expression for the received signal of the desired user, denoted as r_o, as:

$$r_o(t)=\sum_{i=1}^{U}\sum_{j=1}^{N}\sqrt{\frac{2Po}{N}}\alpha_{i,j}b_{o,i}(t)g_o(t)c_o[j]\cos(2\pi f_{i,j}t+\Phi_{i,j})+$$

$$\sum_{k=1}^{KA}\sum_{i=1}^{U}\sum_{j=1}^{N}\sqrt{\frac{2Pk}{N}}\alpha_{i,j}b_{k,i}(t)g_k(t)c_k[j]\cos(2\pi f_{i,j}t+\Phi_{i,j}) + n(t) \qquad (4.2)$$

Here, $\alpha_{i,j}$ is the amplitude of the channel for the ith substream's jth subcarrier.

n(t) is the double sided additive white Gaussian noise (AWGN) having power spectral density $N_o/2$.

As in [18]-[19], the data bits carried by the same subcarrier in assumed to be having Rayleigh flat fading channel.

Now, in the figure below, we can see the receiver structure of the two dimensional time domain and frequency domain spreading MC-DS-CDMA:

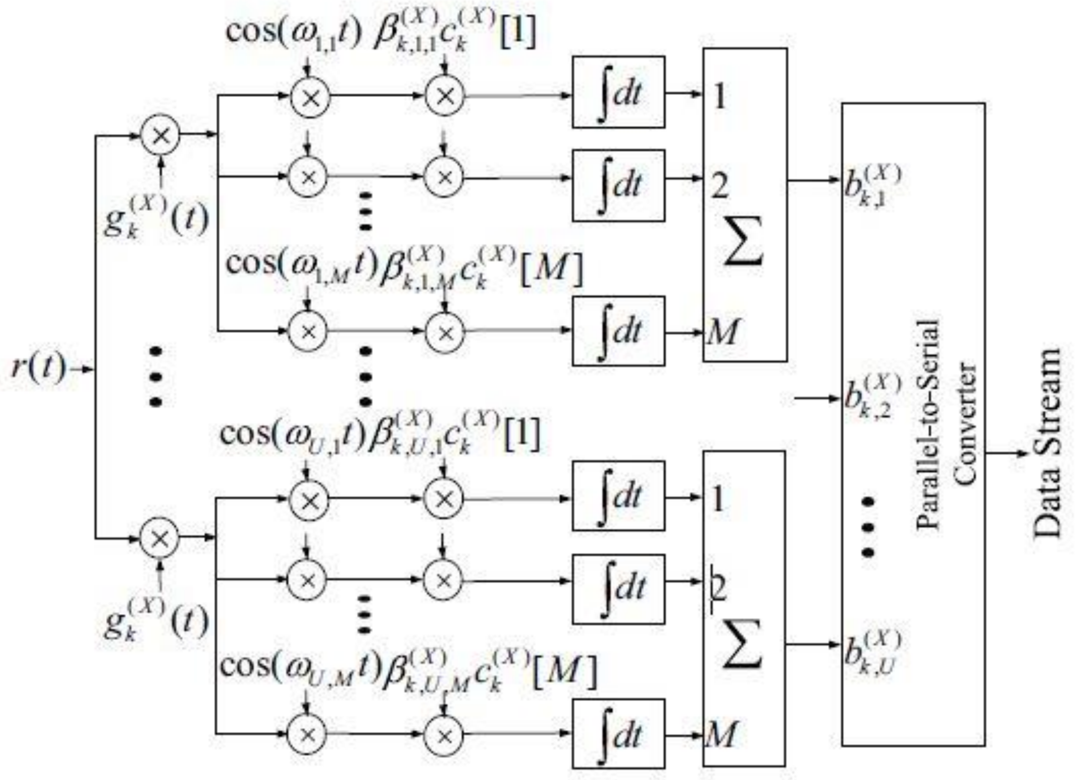

Fig4.2: receiver structure of two dimensional spreading codes MC-DS-CDMA

For the information data bits of the reference user $b_{k,i}[h]$, let us assume that the first bit in the sth substream is the bit of interest, i.e. $b_{o,s}[0]$. What we get after the time domain dispreading will be the signal which is rth subcarrier of the sth substream in the information signal of the reference user. The time domain despreaded signal can be written as:

$$Y_{o,s,v} = \int_{0}^{T_o} r_o(t)\beta_{s,v} g_o(t) c_o[v] \cos(2\pi f_{s,v} t + \Phi_{s,v})$$

$$= \sqrt{\frac{P_o}{2M}} T_o \left\{ b_{o,s}[0]\alpha_{s,v}\beta_{s,v} + \sum_{k=1}^{Kx} I_{k,s,v} + n_{s,v} \right\} \qquad (4.3)$$

Where, P_o is the transmitted power of the reference user

T_o is the bit duration of the reference user

$\beta_{s,v}$ is the respective weights of a certain taken combining scheme. Here we will be taking maximal ratio combining as the combining scheme.

I is denoting the induced MAI from the user k to the rth subcarrier of the sth substream of the reference user

$n_{s,v}$ is the AWGN which is having zero mean and its variance is $\frac{|\beta o,s,v|^2}{2}(\frac{E}{NNo})^{-1}$ where E_o= P_oT_o denotes the bit energy of the reference user

So, the MAI can be expressed as:

$$I_{k,s,v} = \sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}c_o[v]c_k[v]}{T_o}\int_0^{T_o} b_{k,s}(t)g_k(t)g_o(t)dt \quad (4.4)$$

For the frequency domain dispreading, we are combining N subcarriers using maximal ratio combining scheme, which makes the decision variable of $b_{o,s}[0]$ of the reference user as:

$$Y_{o,s}=\sum_{v=1}^{N} Yo,s,v \quad (4.5)$$

The further impacts of MAI will be analyzed in the further discussions in upcoming chapters.

4.2 Simulation Results:

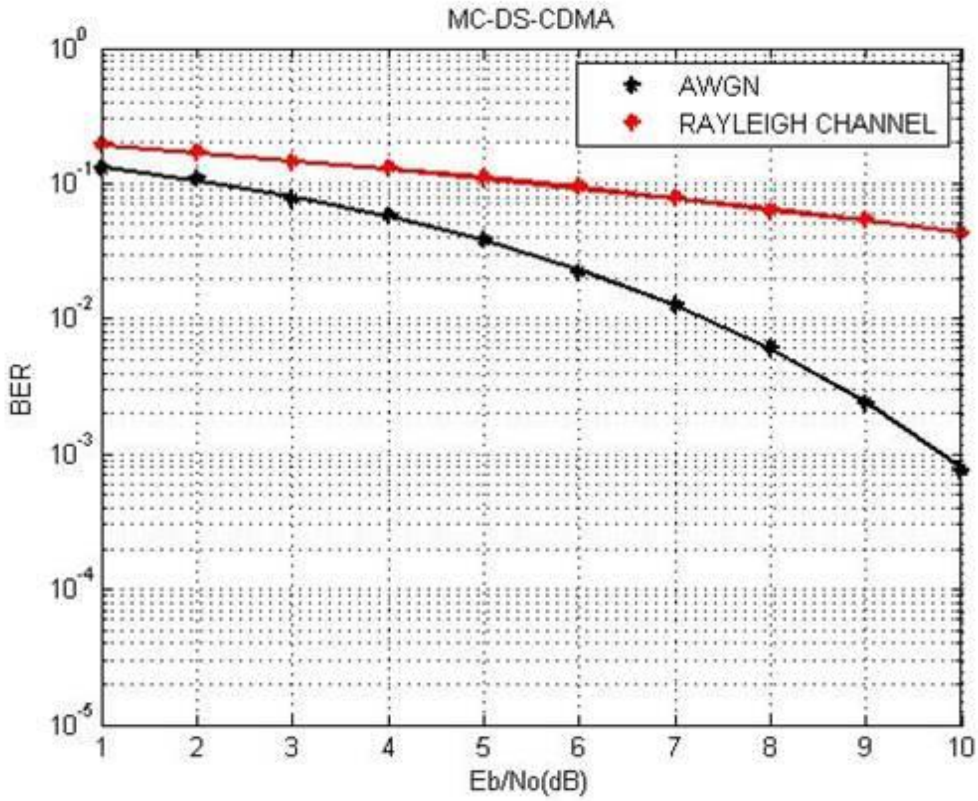

Fig 4.3 BER response for MC-DS-CDMA

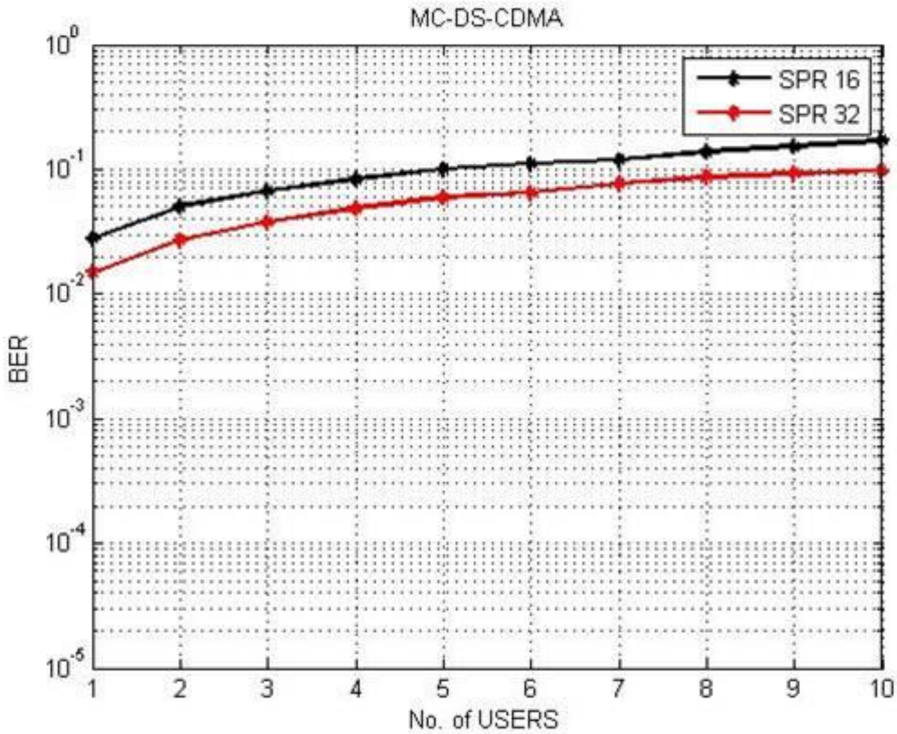

Fig 4.4 BER vs no. of users for MC-DS-CDMA

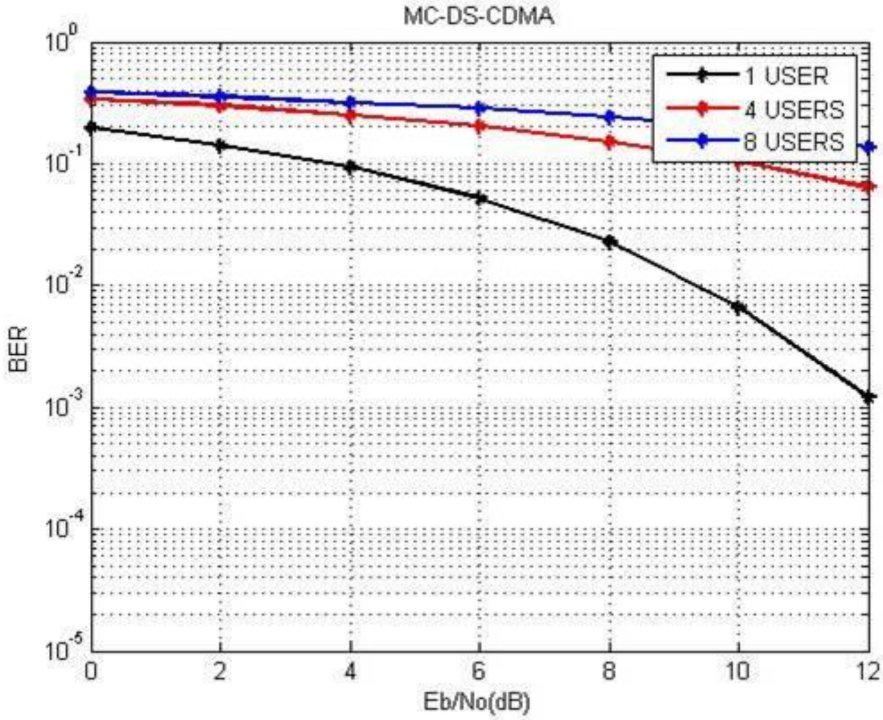

Fig 4.5 BER response of MC-DS-CDMA for multiple users

5
Multiple Access Interference

This section will analyze the multiple access interference on multicarrier MC-DS-CDMA and method to suppress the MAI. To look into the MAI $I_{k,s,v}$, we have to have top to bottom thought regarding the relationship between the bit length of time of the reference client and the bit span of the client which is meddling i.e relationship between T_o and T_k for kth interfering user. Now, there can two possible cases. One, if the data rate of the interfering user is greater than the reference user and second, if the data rate of the interfering user is less than that of the reference user.

5.1 Basics

5.1.1 MAI from high data rate users (T_O>T_K):

Let us consider the ratio of the bit duration of the reference user to that of the interfering user be $L_k=T_o/T_k$ and it is a positive integer. Then we can the MAI as:

$$I_{k,s,v}=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_o}\int_0^{T_o} b_{k,s}g_k(t)g_o(t)dt$$

$$=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_kL_k}\sum_{l=0}^{L_k-1} b_{k,s}[l]\times\int_0^{T_k} g_k(t)g_o(t)dt \qquad (5.1)$$

Since, the value for $\int_0^{T_k} g_k(t)g_o(t)dt$=1 for non-orthogonal time domain spreading codes, the above expression for MAI can be written as:

$$I_{k,s,v}=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_k L_k}\sum_{l=0}^{L_k-1} b_{k,s}[l] \quad (5.2)$$

Where, $b_{k,s}[l]$=±1 having probability

5.1.2 MAI from low data rate users ($T_O \leq T_K$):

We know, the expression for MAI is given as:

$$I_{k,s,v}=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_o}\int_0^{T_o} b_{k,s} g_k(t) g_o(t) dt$$

$$=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_k L_k} b_{k,s}[0]\int_0^{T_k} g_k(t) g_o(t) dt \quad (5.3)$$

As similar to the case in high data rate users, here also, due to time domain spreading codes being non-orthogonal, we can say that

$$\int_0^{T_k} g_k(t) g_o(t) dt=1 \quad (5.4)$$

The MAI can now be written as:

$$I_{k,s,v}=\sqrt{\frac{P_k}{P_o}}\frac{\alpha_{s,v}\beta_{s,v}C_k[v]C_o[v]}{T_k L_k} b_{k,s}[0] \quad (5.5)$$

5.2 MAI coefficient:

A new performance metric has been characterized in order to quantize MAI on each of the channel code. We name that metric as: MAI Coefficient. Here, as we know, we have considered downlink transmission of single cell, all the interferers encounter the same blurring channel as the reference client. The main distinction between these interferers is the amount of interference they create. The MAI can be written as:

$$\gamma = \sum_{k=1}^{K_A} \sum_{l=0}^{L_k-1} \frac{R_k}{R_o(L_k)^2} \left[2P_o G_o \sum_{v=1}^{M} |\alpha_{s,v}|^4\right] \quad (5.6)$$

As shown in the above equation, the impacts of the channel from other clients won't add to the MAI forced on the coveted client. Since the downlink MAI is come about because of the subcarriers of reusing TDSC in distinctive recurrence of frequency domain spreading code trees, here we are assuming all the Rayleigh fading parameters are independent in the above given equation. With respect to the reference user, we can see that, for all the interfering users, $2P_o G_o \sum_{v=1}^{M} |\alpha_{s,v}|^4$ term is common. As a result, only the term $\sum_{k=1}^{K_A} \sum_{l=0}^{L_k-1} \frac{R_k}{R_o(L_k)^2}$ can be used to define the MC-DS-CDMA in downlink MAI environment.

There can be two possible scenarios, as discussed above:

5.2.1 MAI from high data rate users:

Here, we can see the ratio of the data rate of the interfering users and the reference user, as seen below,

$\frac{R_k}{R_o} = \frac{T_o}{T_k} = L_k$ is greater than 1. Therefore, we can follow it as

$$\sum_{k=1}^{K_A} \sum_{l=0}^{L_k-1} \frac{R_k}{R_o(L_k)^2} = \sum_{k=1}^{K_A} \sum_{l=0}^{L_k-1} \frac{1}{L_k} = \sum_{k=1}^{Ka} 1 \quad (5.7)$$

5.2.2 MAI from low data rate users:

As assumed above, here also, we can take L_k=1, and hence we can derive the MAI from low data rate users as:

$$\sum_{k=1}^{K_A} \sum_{l=0}^{L_k-1} \frac{R_k}{R_o(L_k)^2} = \sum_{k=1}^{K_A} \frac{R_K}{R_o} \tag{5.8}$$

A point worth noting is that the ratio of data rates of interfering users and that of the reference users is less than one.

Now, after the combination of the above two equations of high data rates as well as low data rates, the downlink MAI coefficient in MC-DS-CDMA having time and frequency domain spreading can be defined as:

$$k = \sum_{k=1}^{K_A} \min(1, \frac{R_k}{R_o}) \tag{5.9}$$

In the grid representation, we saw how the data rate of the requested user is directly proportional to the area of the rectangular boxes in the grid. Using that idea, we can rewrite the MAI coefficient as:

$$k = \sum_{k=1}^{K_A} \min(1, \frac{\sigma_k}{\sigma_o}) \tag{5.10}$$

Where, σ_k and σ_o are area of the rectangular boxes of the interfering user as well as reference user respectively. Also, one point which can be noted the difference between real MAI and our MAI coefficient is $2P_oG_o \sum_{v=1}^{M} |\alpha_{s,v}|^4$

5.3 Interference avoidance strategy:

Instantly we propose MAI-coefficient-based impedance avoiding methodology. With the aide of the MAI coefficient, the proposed technique can quickly and adequately survey the offer of each spreading code, get the best possible appointment of all the plausible codes and pick one which realizes less MAI. The goal of the interference avoidance strategy is to lessen the MAI impact in the MC-DS-CDMA framework, while keeping the code tree smaller to keep up low call blocking performance for clients with different information data rates. On a basic level, the proposed interference avoidance strategy comprises of three stages. The flow diagram shown in figure explains the strategy in brief.

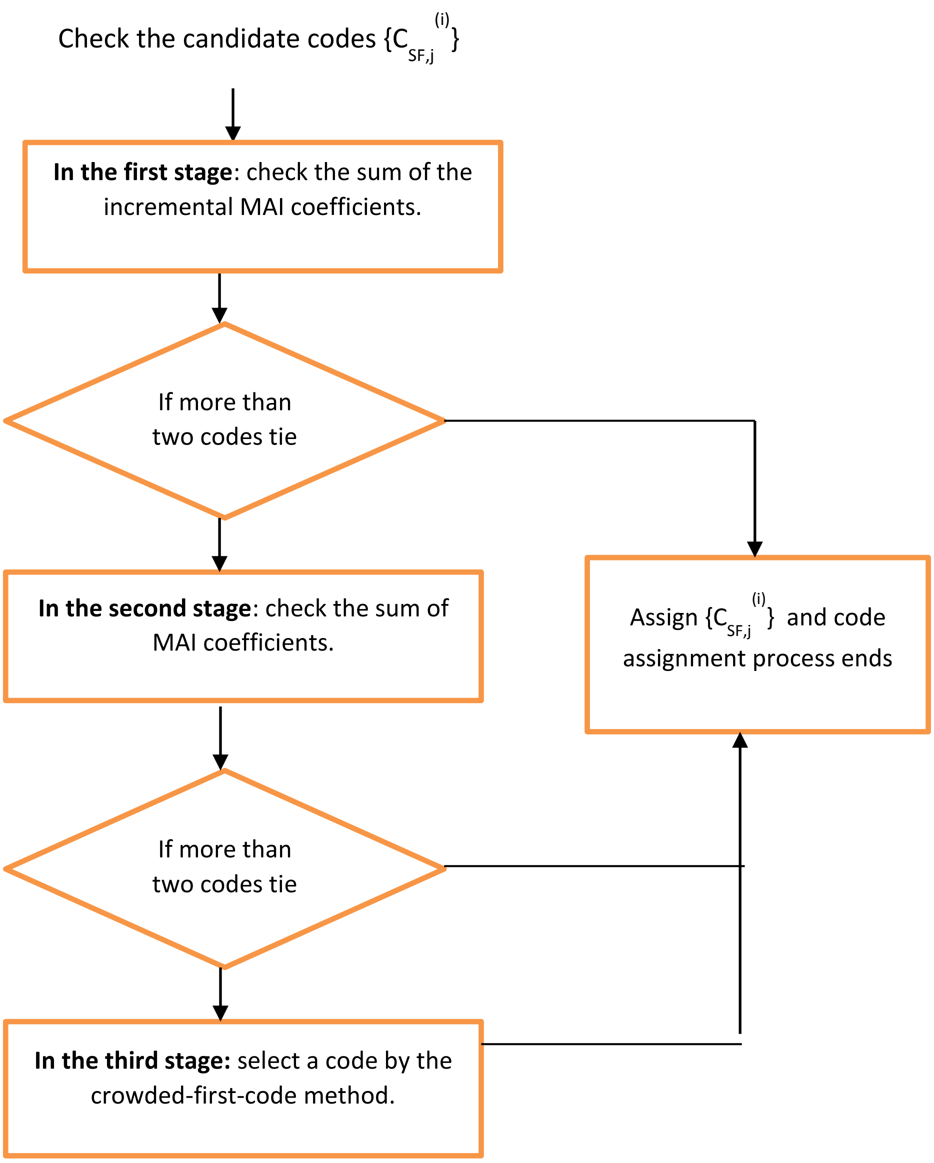

Fig 5.1 Flow diagram to show Interference Avoidance Strategy

As we can see in the figure above, in the very first stage, our task is to check the incremental sum of the MAI coefficient for the requested candidate code. In the second stage, in case there is a tie between the incremental codes, then the comparison of the sum of the incremental MAI is done. At last, if again there is a tie, then code assignment is done according to the crowded first code assignment method. The strategy has been discussed below in detail.

Let is consider that the set of candidate codes having their respective gains of TDSC as M and FDSC as N be denoted as $\{C_{M,j}^{i}\}$ where $1 \leq i \leq N$ and $1 \leq j \leq M$. The set of related codes of the candidate codes is denoted as $R_c\{C_{M,j}^{i}\}$. So, the candidature of a code for a requested data rate is done using following three stages:

5.3.1 First stage:

The incurred MAI of utilizing code $C_{M,j}^{i}$ is assessed by the entirety of the addition of the MAI coefficients of codes in $R_c\{C_{M,j}^{i}\}$. If in case, there is a tie in the addition of the incremental coefficients of MAI, then we will move to the second stage. Otherwise, we will select that incremental MAI which is having smallest sumc. in the set of the $R_c\{C_{M,j}^{i}\}$. The detailed explanation of the first stage is summarized below:

a. The nth code in $R_c\{C_{M,j}^{i}\}$, denoted as $C_n \in R_c\{C_{M,j}^{i}\}$, will have its calculation of increments of the MAI coefficients.

b. The sum of the incremental MAI coefficients is denoted by $\Delta_k(R_c\{C_{M,j}^{i}\})$, for as $C_n \in R_c\{C_{M,j}^{i}\}$. Then we can write as:

$$\Delta_k(R_c\{C_{M,j}^{i}\}) = \sum_{C_n \in R_c\{C_{M,j}^{i}\}} \Delta_k(C_n) \tag{5.11}$$

c. That code must be selected which is having $\min\{\ \Delta_k(R_c\{C_{M,j}^{i}\})\ \}$.

d. The process will end here and there will be no need to go in the further stage if ther is only one candidate code with Δ_k(R$_c\{C_{M,j}^{i}\}$).

5.3.2 Second stage:

In the second stage, in the related codes of the candidate code, i.e. R$_c\{C_{M,\beta}^{\alpha}\}$, their sum of MAI coefficients is compared, where, $\{C_{M,\beta}^{\alpha}\}$, is the set of codes having the exact sum of MAI coefficients increments. Again, if there is tie in codes, the process goes further to third stage. The rules in the second stage can be detailed as follows:

a. Similar to the process in first stage, calculation of MAI coefficient of nth code of R$_c\{C_{M,\beta}^{\alpha}\}$, and is denoted as $k(C_n)$

b. The sum of $k(C_n)$ is denoted by k(R$_c\{C_{M,\beta}^{\alpha}\}$) an can be written as:

$$k(\mathrm{R_c}\{C_{M,\beta}^{\alpha}\}) = \sum_{\mathrm{Cn}\,\in\,\mathrm{Rc}\{C_{M,\beta}^{\alpha}\}} k(C_n) \tag{5.12}$$

c. The codes having min(k(R$_c\{C_{M,\beta}^{\alpha}\}$)) shall be picked.

d. If there is only one code fulfilling the above requirements, then assign that code and there will be no need to go to further steps.

5.3.3 Third stage:

In the third step, a code in $C_{M,\delta}^{\gamma}$ is selected according to already discussed crowded first code assignment strategy, where $C_{M,\delta}^{\gamma}$ is the set of codes which are having same number of incremental MAI coefficients as seen in step two.

5.4 Simulation Result:

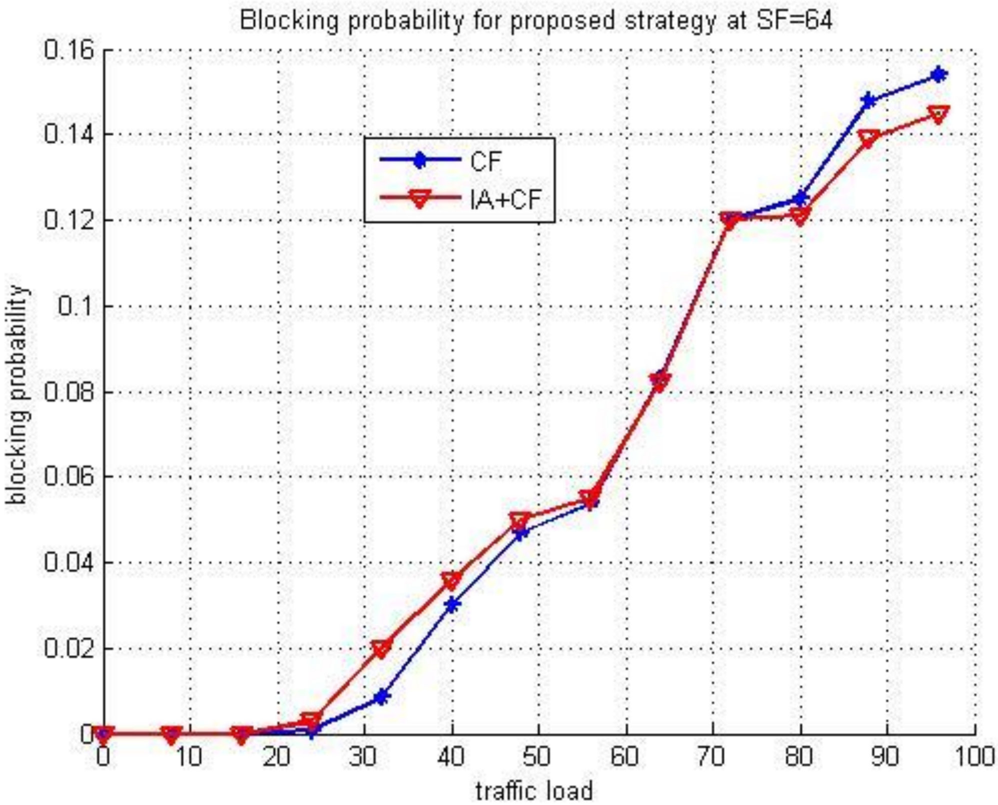

Fig. 5.2 Comparison of Crowded first strategy with proposed strategy

From the above result we can say that, there is very slight effect in the blocking probability of the system due to our proposed interference avoidance code assignment strategy when compared to the crowded first code assignment strategy.

6

Conclusions and Future work

6.1 Conclusions:

For the two dimensional time domain and frequency domain spreading in MC-DS-CDMA, we have simulated the BER response for single as well as multiple users. In addition, we have introduced a new performance metric- MAI coefficient and with the help of that coefficient, we have proposed interference avoidance code assignment strategy we have been able to compare the code blocking probability with other code blocking probability. In the thesis, we can draw following conclusions for our new proposed strategy:

1. In the three types of code assignment strategy, namely, random, leftmost and crowded first code assignment strategy, crowded first strategy gave the best performance for call blocking probability followed by leftmost and then random strategy.
2. The new interference code assignment strategy doesn't affect the code blocking performance as compared to the crowded first code assignment strategy.

6.2 Future Work:

In the OVSF code assignment strategy, we have only done code placement. But if we can replace a code to different position, which can increase the capacity of the code tree. This phenomena is known as code replacement technique

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